Modeling the Limits and Effects of Energy Extraction from Tidal Streams

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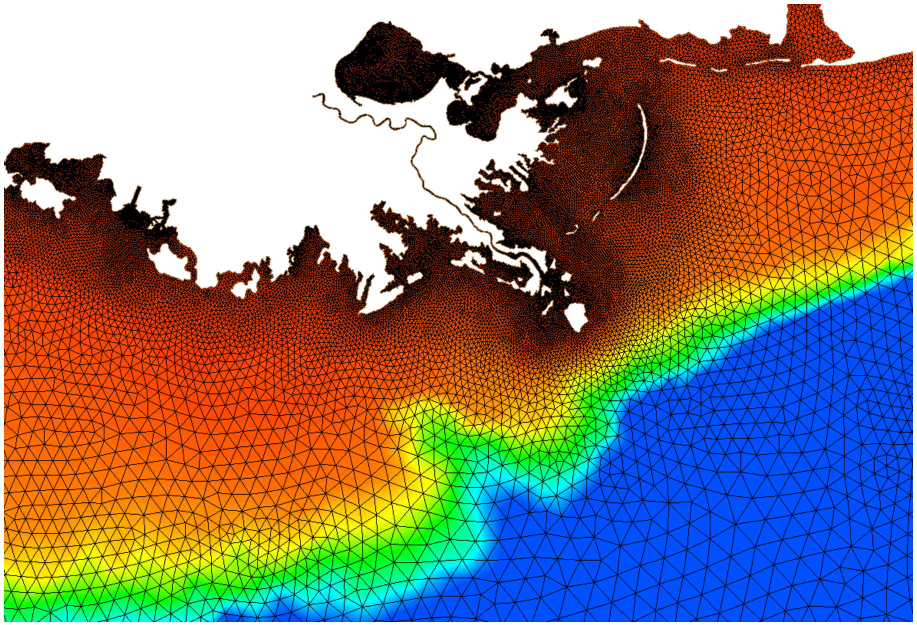
Far-field Modeling Support to Accelerate MHK Energy Deployment

- Energy resource assessment
  - Maximum and practical extractable energy
- Environmental impacts
  - Flow fields
  - Flushing time
  - Biogeochemical transport processes
- Efficiency of energy extraction
  - Array optimization and device siting
  - 3-D effects
- Permitting process
  - Clean Water Act

Coastal Ocean Model – FVCOM

- 3D Finite Volume Coast Ocean Model (FVCOM)
- Unstructured grid – best suited for complex geometry
- MHK module developed by PNNL
- Wetting and drying simulation
- Baroclinic simulation
- Water quality
- Sediment transport
- Coupled wave model
- Public domain
- Parallel computation



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MHK Modeling Approach

- Implementation of MHK energy device in FVCOM using momentum sink approach
- Governing equations with MHK effect

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_o}\frac{\partial P}{\partial x}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_u\boxed{-F_{MHK-u}}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_o}\frac{\partial P}{\partial y}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_v\boxed{-F_{MHK-v}}$$

- Momentum sinks
  - Turbine blades $$S_1=-\frac{1}{2}(C_T+C_b)A_b|\vec{u}|^2$$
  - Supporting structure $$S_2=-\frac{1}{2}C_pA_p|\vec{u}|^2$$
  - Turbine foundations $$S_3=-\frac{1}{2}C_fA_f|\vec{u}|^2$$

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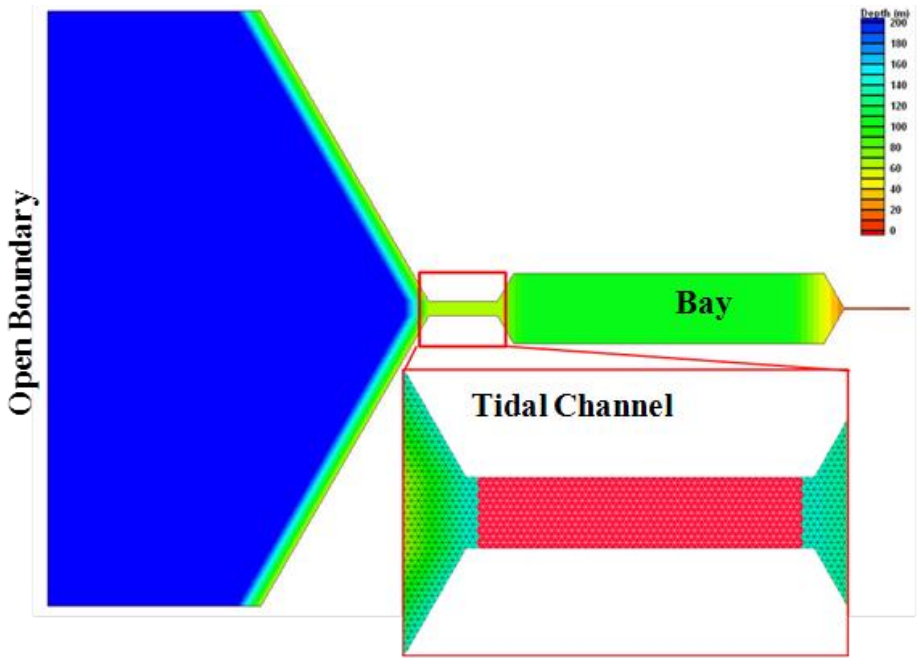
Technical Approach

Validation to analytical solution

- Idealized tidal channel and bay with realistic dimensions and forcing
- Open boundary M2 tide (2m range)
- User-friendly MHK parameter input
  - — Turbine elevation from seabed
  - — Turbine diameter
  - — Turbine thrust coefficient
  - — Turbine blade drag coefficient
  - — Areas of supporting poles and base
  - — Drag coefficients for poles and base

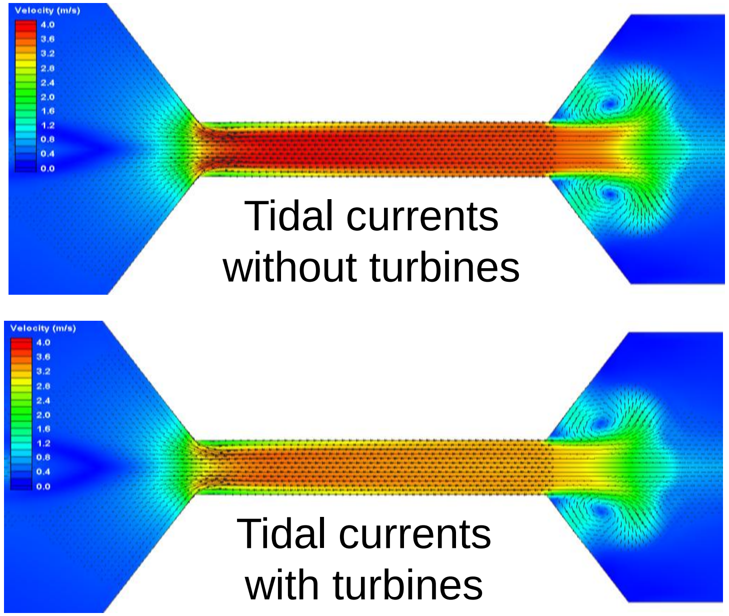


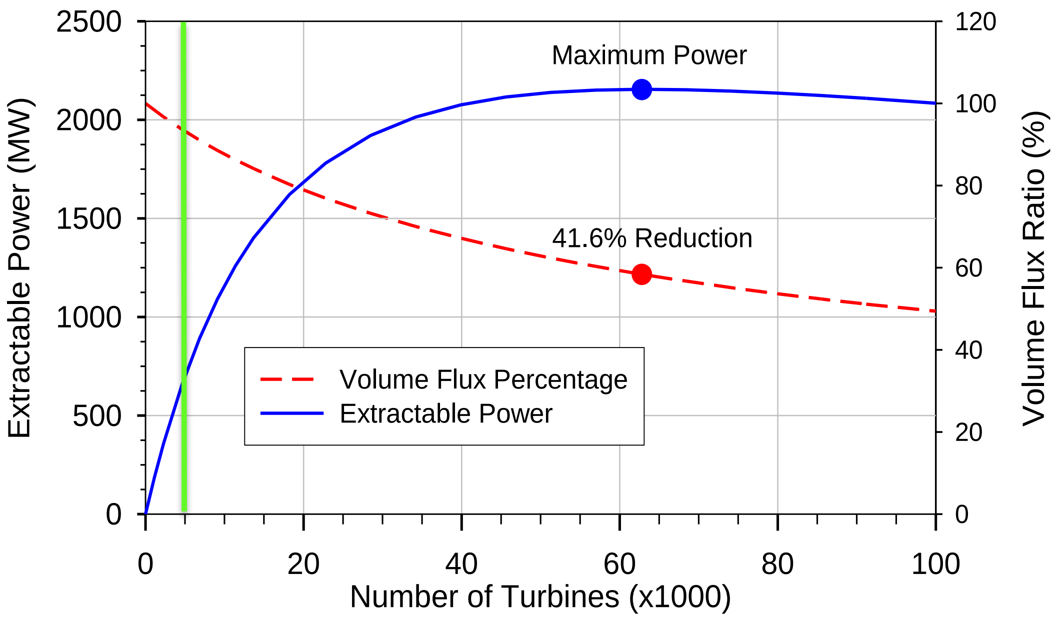
Open Water	Channel Dimension (m)			Basin Dimension (m)		
Depth (m)	Length	Width	Depth	Length	Width	Depth
200	30,000	6,000	60	150,000	20,000	100

MHK Model Validation

- MHK model results agree well with analytical solution by Garrett & Cummins (2004, 2005)
  - Extractable Max Power = Function of (tidal amplitude, volume flux)

    P_{model} = 2,154 MW; $P_{analytical}$ = 2,169 MW
  - Diminishing return of extractable power occurs when volume flux reduces by 42%

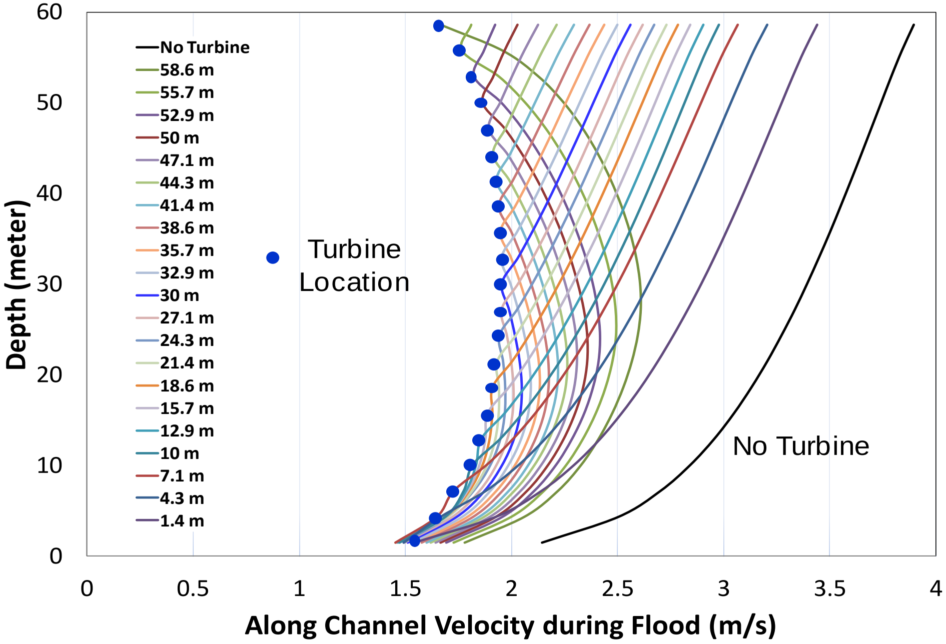




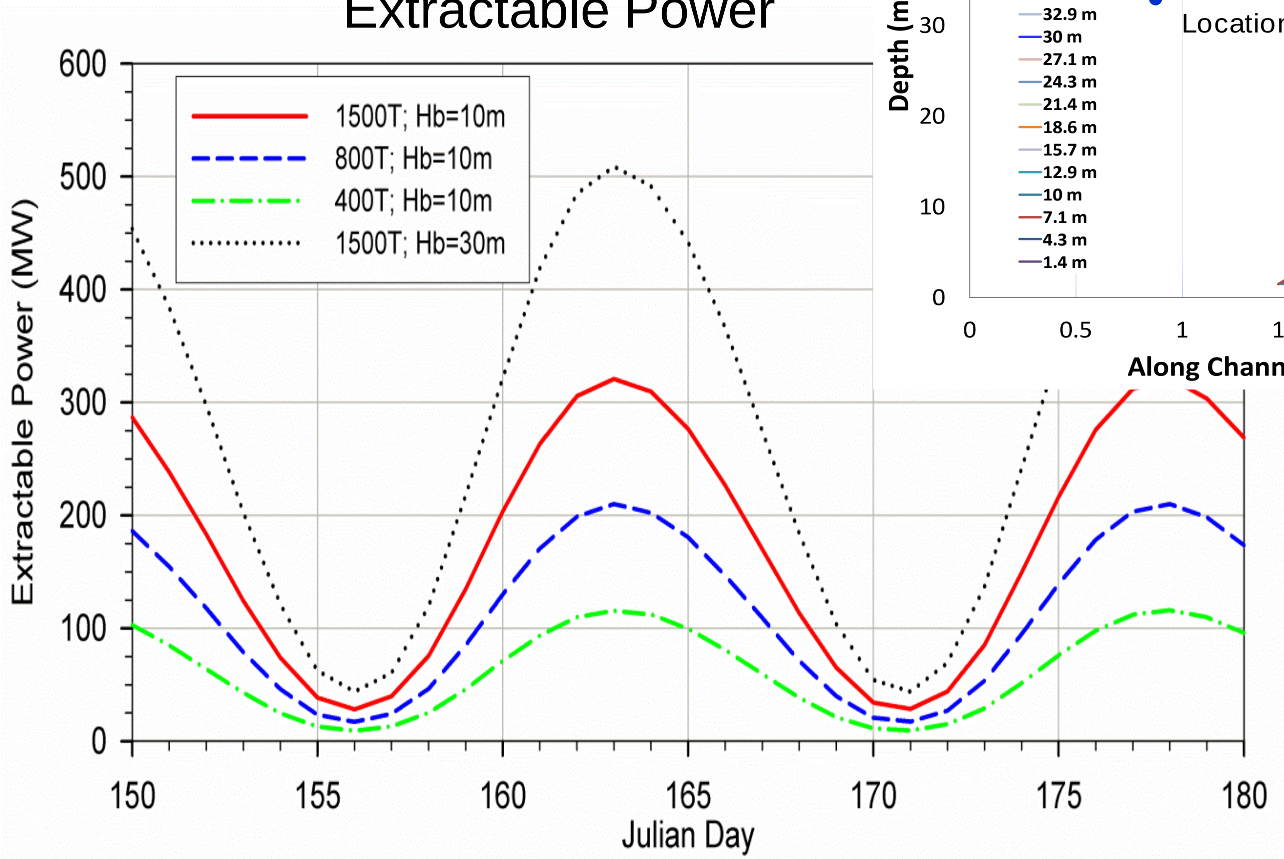
Efficiency – Effects of Hub Height & Array Size

- 3-D modeling approach is needed

Velocity Profiles vs. Turbine Height

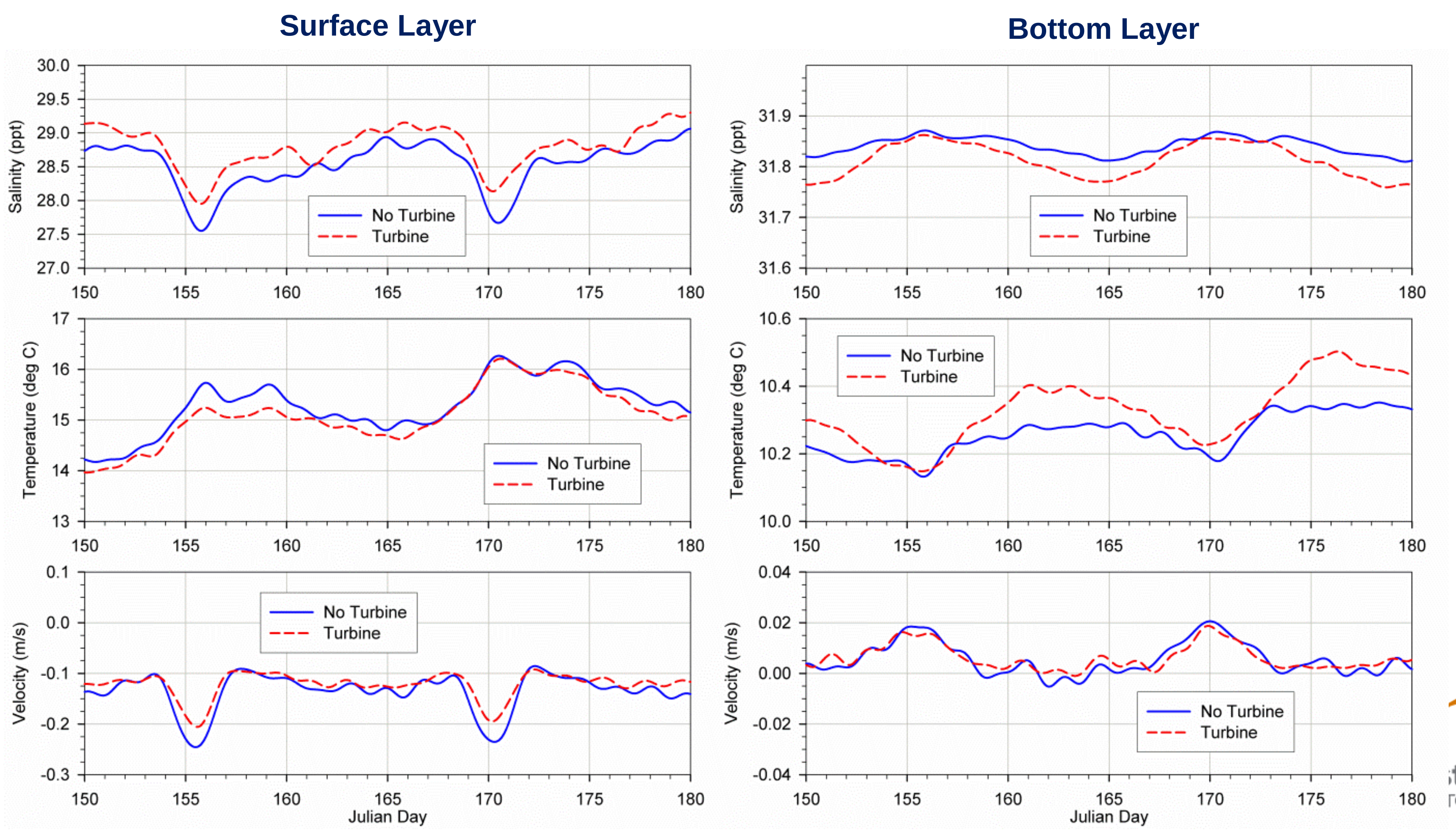


Extractable Power



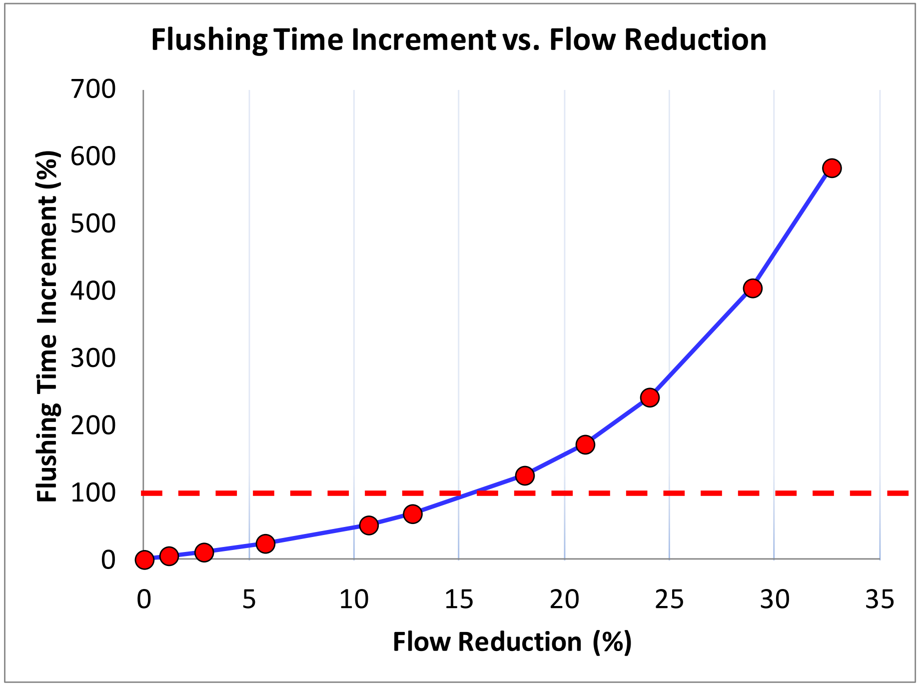
Environmental Impacts – Mixing & Circulation

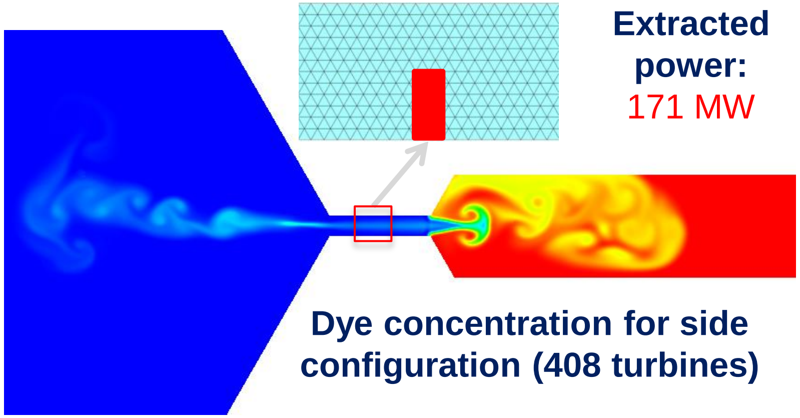
- Year-long simulations of the tidal channel and bay system forced with tide, heat flux and river run-off
  - Tidally-averaged salinity, temperature and velocity in the channel



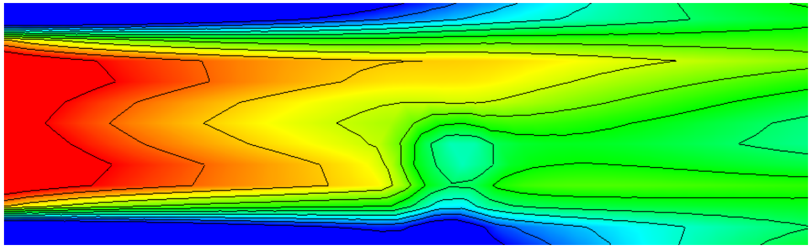
Environmental Impacts - Flushing Time

- Effect on flushing time of a tidal basin – nonlinear effect





Dye concentration for side configuration (408 turbines)



Velocity for MHK Side Configuration

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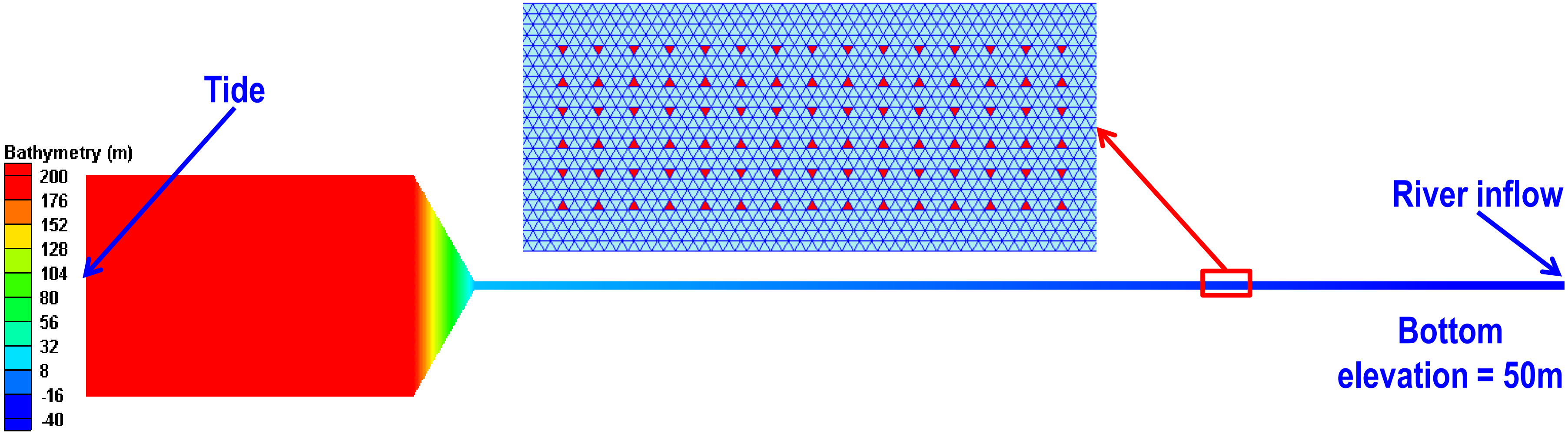
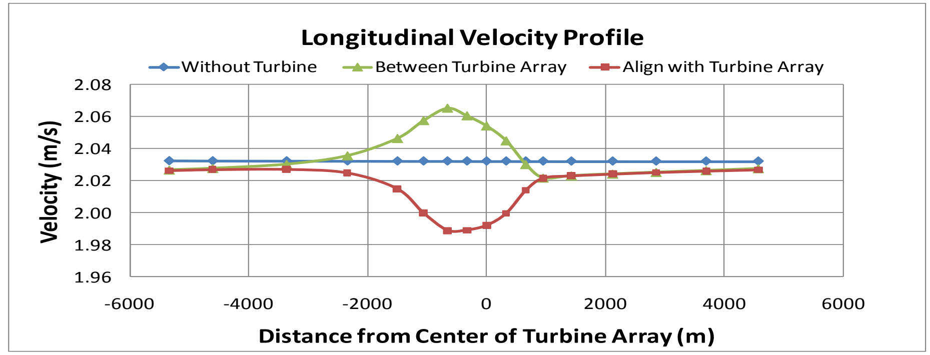
Model Applications - River In-streams

- Energy extraction in river in-streams
  - Cumulative effect and interaction of multiple projects
  - Change of hydrodynamic conditions at local and system scales
- An idealized river connected to a bay forced with tide
  - Bay depth = 200m; length = 100km; width = 750m; slope = 5×10^{-4}
  - 10 projects along the river with 90 turbines per project

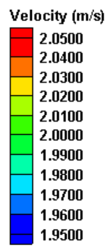


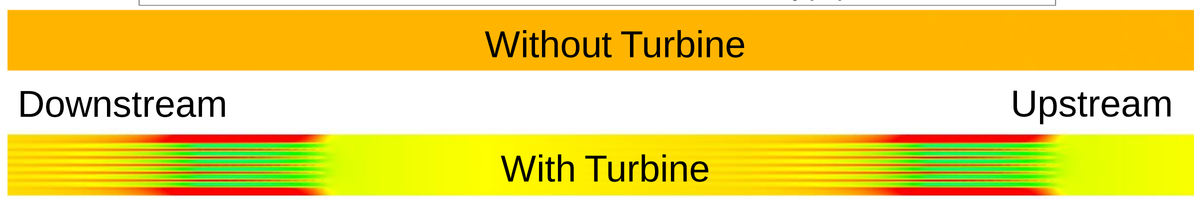
Effect of Energy Extraction on River Streams

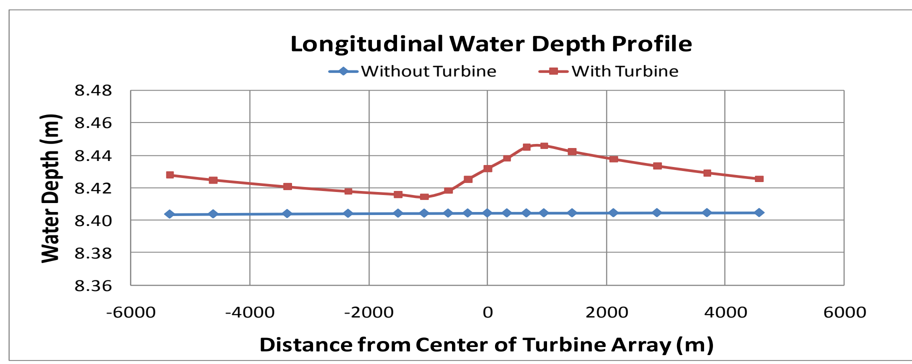
- Effects on local and system-wide scales
  - Slow down the river
  - Increase water level
  - Local variations



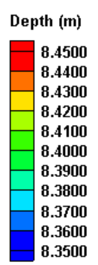
Velocity (m/s)





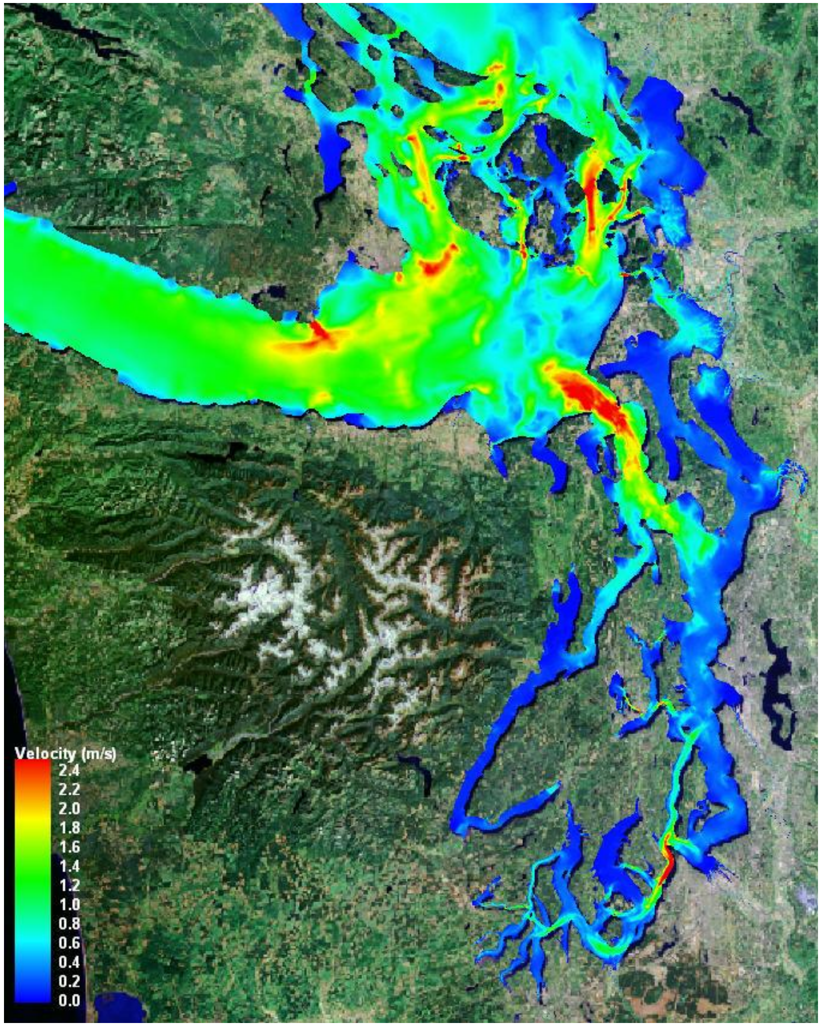


Water Depth (m)

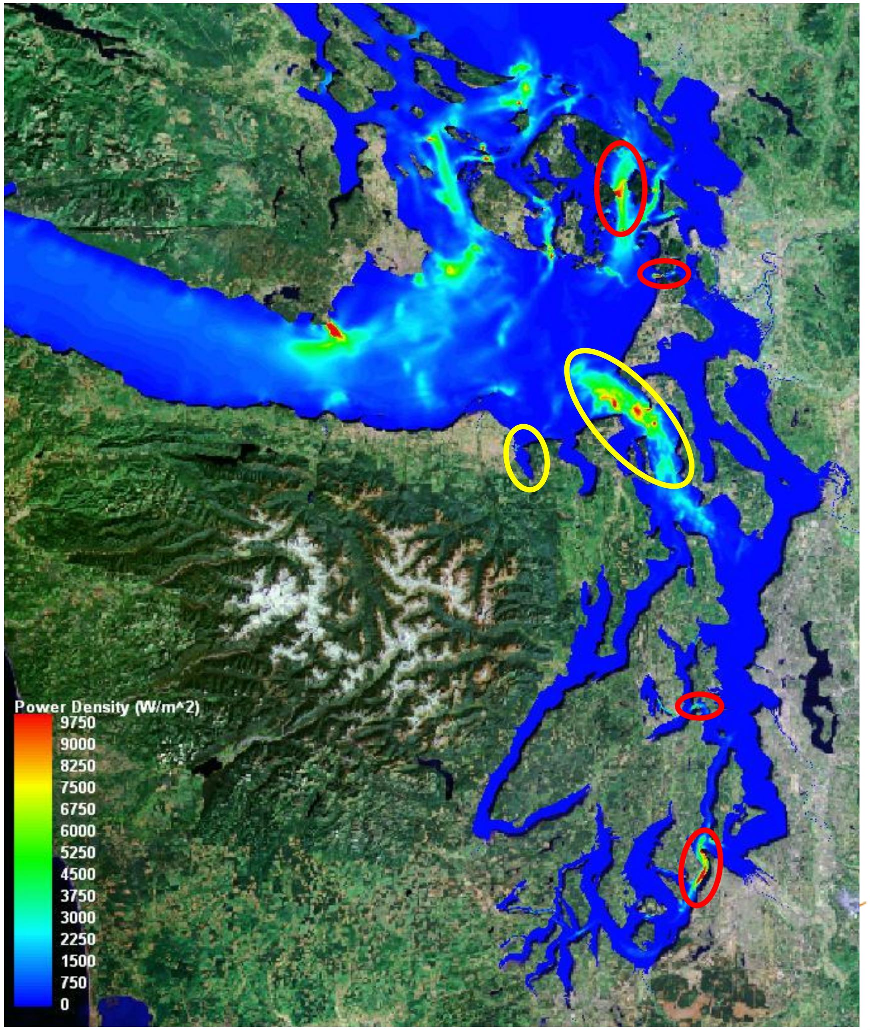


Accelerate MHK Energy Development – Identify Hotspots in the Real World

Tidal Current Magnitude

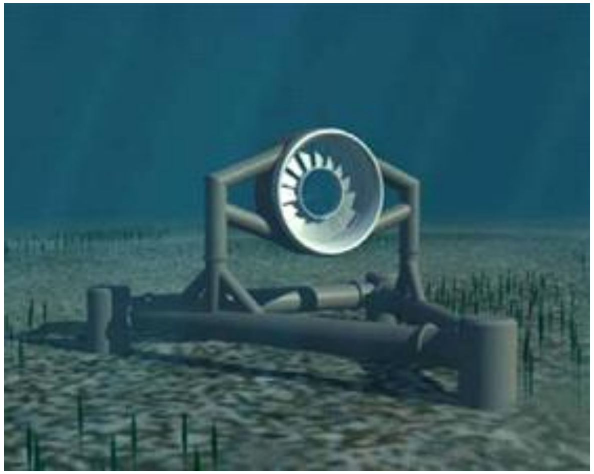


Power Density

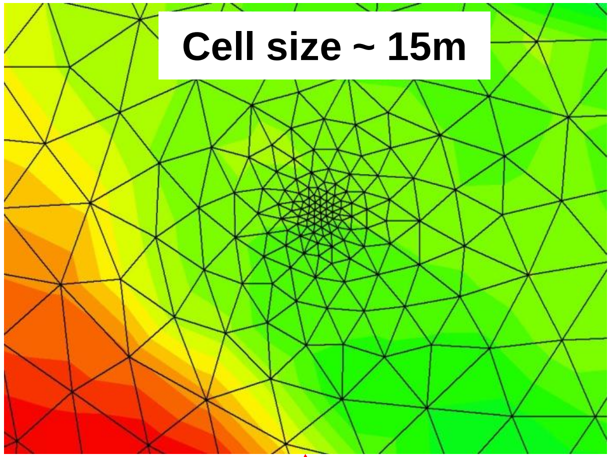


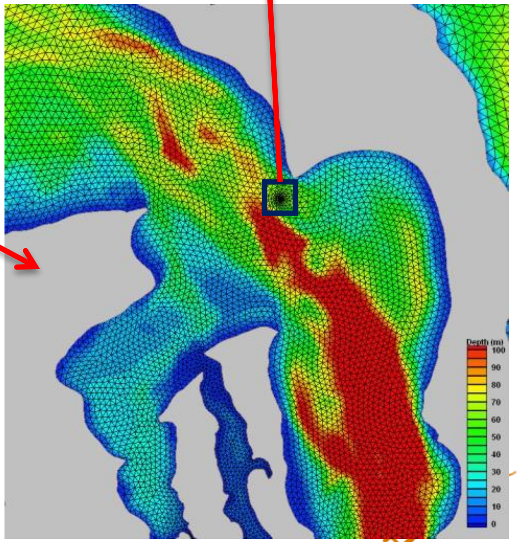
Snohomish PUD Pilot Study in Admiralty Inlet

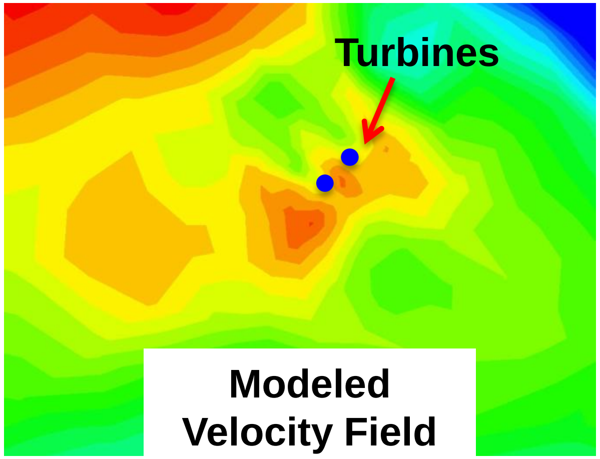
Two Open-Hydro Turbines



Puget Sound Grid







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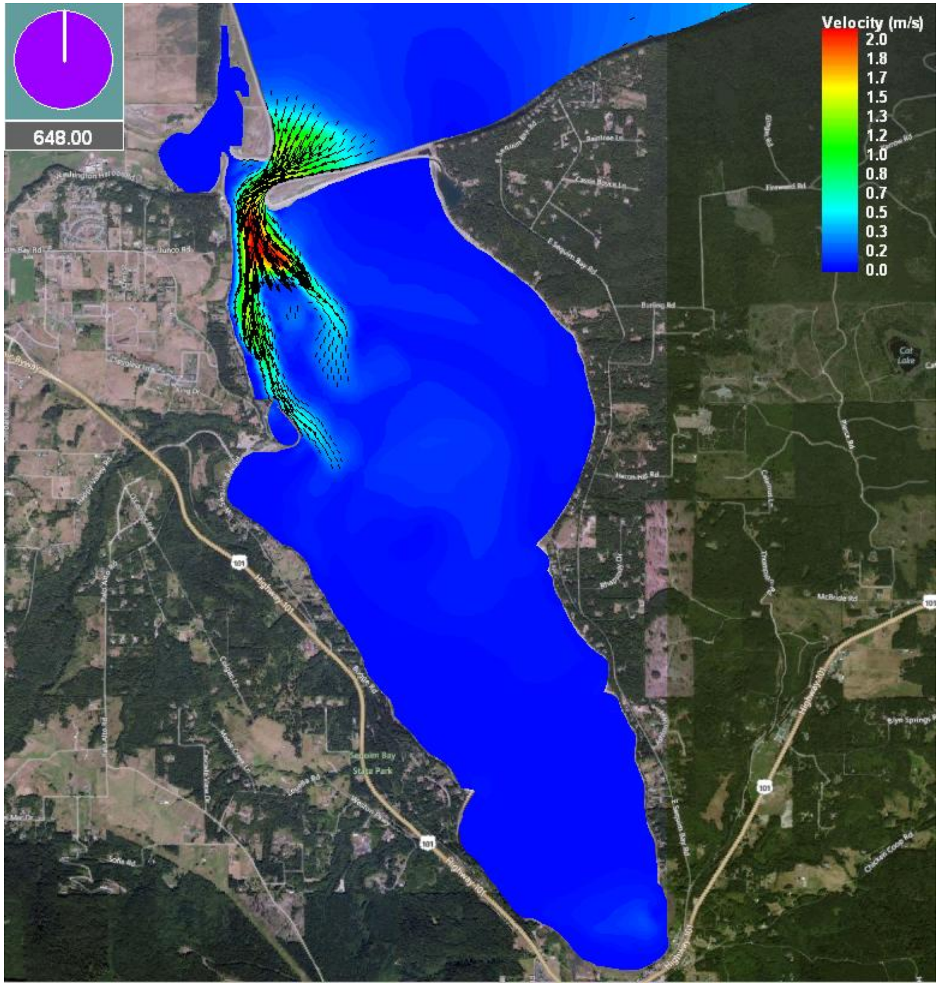

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